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Effects of wind turbines on area use and behaviour of semi-domestic reindeer in enclosures

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Abstract: In recent decades, industrial developments have expanded into reindeer ranges in the arctic and adjacent higher latitudes in search for energy, minerals, timber and other resources. Several wind turbine parks are under planning in reindeer ranges in Norway, and there is concern about possible negative effects on behaviour and area use of wild and semi-domestic reindeer. We tested whether a wind turbine and its rotor movement had any effect on area use, activity changes, vigilance bouts, and restless behaviour like running, walking, and standing for enclosed semi-domestic reindeer. Five different groups of reindeer in a 450 m long, 8 hectare, enclosure close to a wind turbine were manipulated by turning the wind turbine rotor on and off, and compared with reindeer in a control enclosure without wind turbine exposure. When exposed to rotor movement, two groups used locations farther from the wind turbine, two groups showed no shift, while one group moved closer to the wind turbine. The reindeer showed no systematic differences in the measured behaviour patterns between the two enclosures that could indicate fright or stress as a consequence of the wind turbine or rotor movement. We conclude that semi-domestic reindeer in an enclosure showed no negative behavioural response and little or no aversion towards a wind turbine. The possibility of rapid habituation in a small enclosure with continuous wind turbine exposure suggests that effects on area use should be studied at a larger scale or with free-ranging reindeer.

Key words: activity changes, aversion, disturbance, exposure, vigilance, wind turbine rotor.

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Introduction

In recent decades, industrial developments have expanded into the arctic and adjacent higher latitudes in search for energy, minerals, timber and other resources (Klein, 2000). Reindeer's (*Rangifer tarandus*) dependence on large areas for grazing and regional movement patterns make them vulnerable to increases in human development and activity in their habitats. In Norway, large hydroelectric developments have resulted in loss of pastures for wild and semi-domesticated reindeer (Skogland & Mølmen, 1980; Reimers, 1986). Human infrastructure and activity combined with a rugged terrain with deep valleys and wildlife management decisions have resulted in the creation of 26 subpopulations of wild reindeer in southern Norway, some of which are restricted to one range for all seasons (Gaare, 1968; Skogland & Mølmen, 1980). Although anthropogenic development has increased significantly over the last 50 years and is forecasted to continue increasing, there is uncertainty about the separate effect of different types of disturbing factors, and the cumulative effect of several disturbing factors (Klein, 2000; Reimers *et al.*, 2000).

In recent years, alternative energy production from wind turbines has received political support in Norway, with a goal of producing 3 TWh within year

Table 1. Periods with wind turbine (W.t.) rotor turned on and off and number of observations during experimental periods with different groups of reindeer.

Enclosure	Year	Exp. period	Date	Number of reindeer	Group of reindeer	Rotor	Scan obs.	Focal obs.
W.t.	1999		14.09–20.09	five	A	Off	1661	53
W.t.			20.09–28.09	five		On	1975	64
W.t.			28.09–02.10	five		Off	1080	43
W.t.			02.10–07.10	five		On	1219	44
W.t.			07.10–11.10	five		Off	1159	38
W.t.	2000	1	17.09–20.09	three	B	Off	449	14
Control		1	17.09–20.09	three	C	-	466	10
W.t.		1	20.09–23.09	three	B	On	531	10
Control		1	20.09–23.09	three	C	-	474	11
W.t.		2	25.09–27.09	three	C	Off	342	10
Control		2	25.09–27.09	three	B	-	340	11
W.t.		2	27.09–02.10	three	C	On	798	26
Control		2	27.09–02.10	three	B	-	791	36
W.t.		3	04.10–07.10	five	D	Off	779	24
Control		3	04.10–07.10	five	E	-	725	25
W.t.		3	07.10–13.10	five	D	On	1384	49
Control		3	07.10–33.10	five	E	-	1439	44
W.t.		4	15.10–17.10	four	E	Off	660	28
Control		4	15.10–17.10	five	D	-	537	24
W.t.		4	17.10–22.10	four	E	On	1441	37
Control		4	17.10–22.10	five	D	-	1092	38

2010. Currently, numerous wind turbine parks are under planning in semi-domestic reindeer ranges in Norway. Many of the parks that are under planning in Finnmark county (over 10), Northern Norway (Anonymous, 2001), will consist of up to 100 wind turbines per park, with a minimum distance of 250 m between each wind turbine. There will be roads connecting all the wind turbines as well as power lines and converter stations. Consequently, each wind turbine park may directly or indirectly affect reindeer area use for several km^2.

With the exception of birds (Clausager & Nøhr, 1995), scientific studies on the effects of wind turbines on wildlife are few. To our knowledge, only one systematic study on effects of wind turbines on ungulates has been performed (Johnson *et al*., 2000), in which no difference in abundance of pronghorns (*Antilocapra americana*) within 800 m of a wind turbine park was found when comparing data from before and after construction. A study on possible effects of wind turbines on reindeer was therefore needed.

We performed an experiment with a number of reindeer groups released periodically in two enclosures. One enclosure was located next to a wind turbine, while a control enclosure was without wind turbine exposure. *Rangifer* may respond to human development and activity in two main ways (Wolfe *et al*, 2000); A) they may avoid areas with high levels of development and activity and fail to cross such areas while migrating, or B) they may decrease feeding and increase restless behaviour and energy expenditure near the source of disturbance. If wind turbines were to have a disturbing effect on reindeer, we expected to find:

1) Less use of sections of the enclosure that were closest to the wind turbine.
2) Increased levels of restless behaviour like running, walking and standing, and increased frequency of activity changes and vigilance bouts for reindeer exposed to the wind turbine.

Since no similar studies of wind turbines and wildlife existed, another purpose of this study was to evaluate the suitability of this type of experiment for future studies.

Methods

The experimental area was located at a wind turbine park at Midtre Vikna (10°57’ E 64°52’ N), a hilly

Table 2. The frequency min^{-1} (standard error of the mean (s)) of vigilance bouts in relation to enclosure, reindeer group and rotor movement, for period 3 and 4 in 2000.

Reindeer group	Experimental period	Rotor	Wind turbine Mean vigilance bouts (min^{-1})	Control Mean vigilance bouts (min^{-1})
D	3	Off	0.664 (0.093)	
E				0.484 (0.067)
D		On	0.744 (0.091)	
E				0.745 (0.073)
D	4	Off		0.963 (0.12)
E			0.817 (0.098)	
D		On		0.861 (0.078)
E			0.683 (0.066)	

island with altitudes up to 100 m in Nord-Trøndelag county, in mid-Norway. Vegetation is dominated by birch (*Betula* spp.), graminoids, mosses and lichens. Lichen pasture combined with low snow cover during winter makes it suitable as winter pasture for reindeer, and the Sami reindeer pastoralists have used the area during winter in the 1990s as well as in earlier decades of the 20th century.

In 1991–93, Nord-Trøndelag Electricity Board (NTE) established the wind turbine park, consisting of five wind turbines. The individual wind turbines have a tower height of 39 m, a rotor diameter of 39 m and a rotation speed of 30 min^{-1} at wind speeds above 4 ms^{-1}.

The wind turbine enclosure of approximately 8 hectare was located next to the westernmost wind turbine, while the control enclosure of approximately 7 hectare was located about 3 km away from the park. Both enclosures were fenced with 150 cm fence, including the top of the respective hills and stretching 450 m downhill towards southwest (Fig. 1). Although different in shape due to a highly variable terrain, both enclosures had similar vegetation types and climatic conditions. There was a moisture/altitude gradient from the wind turbine / hilltop at 0–50 m distance from the northeast corner of the enclosures, to a level area of bush, meadow and marsh at a distance of 200–450 m. At 300–400 m distance, both enclosures contained a smaller hill with similar vegetation as the area from 0–150 m. At the highest altitudes from 0–150 m distance, and partly from 300–400 m, there were more lichen and heather and less moss and marsh than in the other areas. In parts of the areas from 200–450 m of the wind turbine enclosure, the reindeer could not see the wind turbine. The reindeer grazed on natural pasture throughout the study period.

Study design

Experiments were performed in two field seasons, autumn 1999 and autumn 2000 (Table 1). The field season of 1999 was primarily a pilot study using the wind turbine enclosure only. The effect of the wind turbine was manipulated by periodically turning the rotor on and off. The other wind turbines in the park were not manipulated. These were located 350 m to 800 m away.

Three, four or five, 16–17 months old, female reindeer were used in each enclosure. In 1999, the same reindeer (group A) were observed in the entire study period, while in 2000, there were four separate periods. New reindeer were used in period 1 (group B and C) and 3 (group D and E), while a crossover of reindeer groups between enclosures was performed in period 2 and 4 (Table 1). This in turn provided us with two test groups and two control groups. Unfortunately, all the animals escaped from a broken fence in the wind turbine enclosure during the first day of period 1 when the rotor was off. One new animal from the main herd and two animals from the control enclosure replaced the escaped animals resulting in three animals per enclosure in period 1 and 2. One animal in the wind turbine enclosure was injured during transfer to the wind turbine enclosure in period 2. As a result, data from period 1 and 2 may be less reliable and should be judged with caution.

Observations

At the start of each experiment, the reindeer were released in the enclosure after lasso selection and lorry transport. Human handling of this kind is physiologically stressful and may reduce the animals' glycogen stores (Wiklund *et al.*, 1996). In order to allow the reindeer time to calm down and behave naturally before observations began, we waited minimum 12 hours after the release of the last animal into the enclosures. The reindeer were observed using telescopes, stop-watches with time-split, dictaphones and video cameras. We used digital video cameras mounted on a tripod. Each video recording was continuous and lasted for about 5 min 3 times per hour. There were two observers each simultaneously recording the respective enclosures. The minimum distance to the reindeer during observation was 200 m, and no behavioural effects of observer's presence took place.

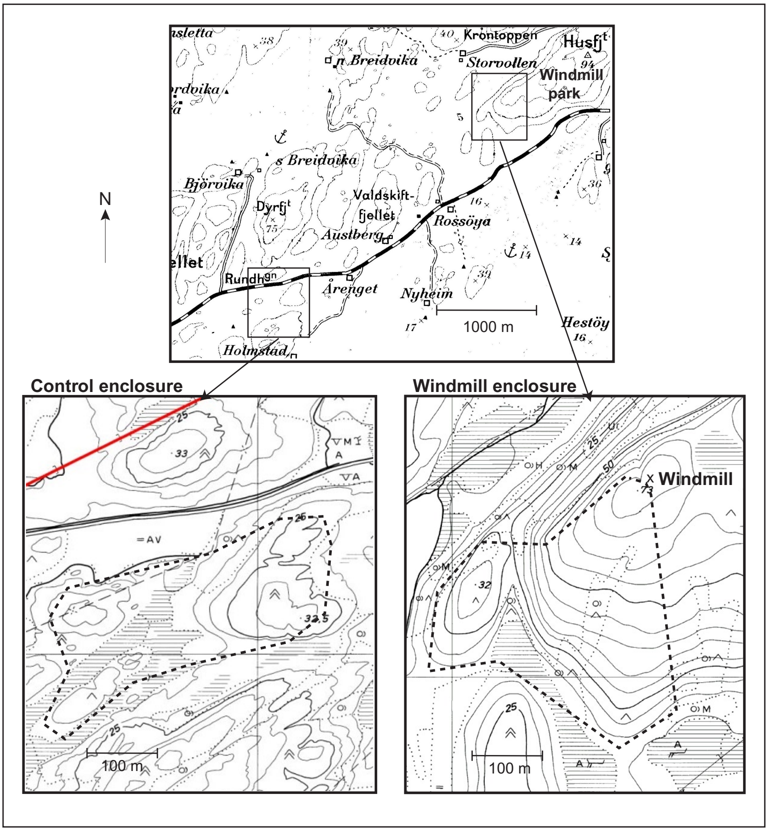

Fig. 1. The enclosures used in the experiment were located at a wind turbine park at Midtre Vikna (lat 64°52'N, long 10°57'E) in North-Trøndelag County, Mid-Norway. (Permission no. Ugland IT Group-MOT44225).

All observations were done during daylight between 7:00 AM and 8:00 PM. The observations were usually done in three-hour shifts, with one-hour break between shifts, *i.e.* three shifts per day.

Reindeer activity and area use in the enclosures were recorded using scan and focal animal sampling (Altman 1974; Murphy & Curatolo, 1986; Mörschel & Klein, 1997; Colman, 2000). A scan was performed every ten minutes by simultaneously observing each reindeer and recording its type of behaviour. During feeding bouts, a focal was performed every twenty minutes by visually observing or video-recording one reindeer closely for 5 minutes. Animal behaviour was categorised into nine types according to Colman (2000). For both scan and focal observations, individual distance to the hilltop/wind turbine in the northeast end of the enclosures was recorded. Animal behaviour during feeding and resting bouts was analysed separately. While resting, the majority of the animals were ruminating at the same location for a lasting period of up to 3 hours. The dominant animal behaviour was lying head up and lying head down. Occasionally, an animal stood while ruminating or stood up and fed shortly before it continued ruminating. We defined a resting bout to last until the majority of the animals had resumed feeding activity lasting for more than 2 minutes or moved to another location.

The video recordings were examined for vigilant behaviour during feeding bouts using methods from Bøving & Post (1997). In the short time period (0–10 min) after the wind turbine rotor was turned on, the reindeer were observed closely to reveal any short-term change of behaviour that could be related to the rotation and noise of the wind turbine rotor.

Wind speed and wind direction was recorded every ten minutes at an observation post on the hilltop next to the wind turbine of the wind turbine enclosure.

Analyses

Variations in behaviour during resting bouts were not considered of importance. The location of the reindeer during resting bouts was recorded, and use of the favourite bedding site was tested in relation to the wind turbine rotor turned on or off. The location of each separate resting bout was treated as an independent observation.

For feeding bouts, temporal autocorrelation in the scan observations was avoided by using one-hour means consisting of maximum 30 individual observations (five animals × six scans). Since animals were occasionally out of sight and because observations during resting bouts were not included, the maximum number of individual observations was not always reached. In the analyses, the one-hour means were proportionally weighted according to number of individual observations. From the scan data, two different response variables were used in the analyses, animal location in the enclosure and restless behaviour. Animal location during feeding bouts was calculated as the mean distance to the wind turbine / hilltop in the northeast end of the enclosures of all individual observations of animals in a one-hour period. Restless behaviour during feeding bouts was calculated as the sum of one-hour mean proportions of running, walking and standing.

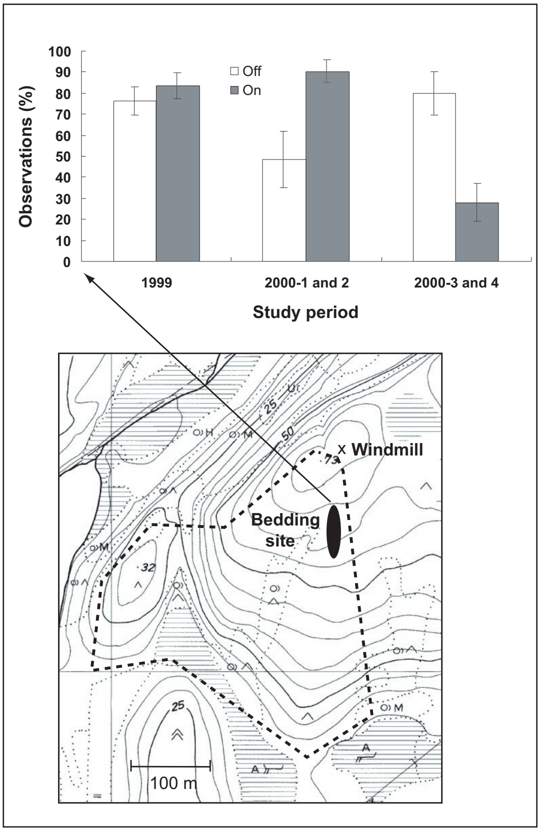

Fig. 2. The total % (bars: standard error of the mean) of observed lying bouts at the most frequently used bedding site of the wind turbine enclosure with rotor movement off and on. (Permission no. Ugland IT Group-MOT44225).

One animal was randomly chosen for each focal observation. The focal observations were not autocorrelated since they were done with 15 minutes separation and only during feeding bouts, *i.e.* the animals changed their behaviour and location for such long time spans that one focal observation did not necessarily depend on the former. If a focal was not 5 minutes long (because the animal occasionally moved out of sight), it was proportionally weighted according to its duration. From focal data, two response variables were used in the analyses: 1) The frequency min^{-1} of activity changes (Mörschel & Klein, 1997; Colman, 2000) and 2) The frequency min^{-1} of vigilance bouts (Bøving & Post, 1997).

Data for 1999, period 1 and 2 in 2000, and period 3 and 4 in 2000 were analysed separately. The following predictor variables were tested for effects on area use and behaviour: Wind turbine, rotor movement, group of reindeer (Table 1), wind speed, wind direction, and interacting effects between the wind turbine rotor movement and wind speed and/or direction. The latter was tested to see if increased noise from the wind turbine in relation to wind speed and direction would affect the reindeer (Solberg, 2000). The continuous predictor variables of wind speed and wind direction were categorised before the analyses. Wind speed was categorised into three levels: 0–4 ms^{-1} (rotor not moving), 4–8 ms^{-1} (rotor noise higher than background noise) and more than 8 ms^{-1} (background noise higher than rotor noise) (Solberg, 2000). The categorisation of wind direction was chosen based on the direction of the enclosures: Southwest (wind towards the wind turbine/hilltop), northeast (wind from the wind turbine/hilltop), northwest and southeast. The effect of wind direction could not be tested in 2000 because the wind was stable from the same direction during most of the study period. The effect of habituation was examined by testing for changes in area use and behaviour after the reindeer had been in the enclosures for 24 hours, and after the rotor had been on for 24 hours.

Reindeer use of the favourite bedding site during resting bouts in the wind turbine enclosure was tested with Fishers exact test for differences in preference between periods with the rotor turned on and off. Reindeer location, restless behaviour, and rate of activity changes and vigilance during feeding bouts were analysed with fixed effects, type III ANOVA. A full model including all predictor variables was the starting point of the analyses. The model was reduced stepwise by removing the nonsignificant predictor variables. In the final model, a significance level of 0.05 was chosen.

Fisher´s exact test and Analyses of variance (ANOVA) were performed in S-PLUS 2000 Professional. The data were checked for normality and constancy of variance through QQ-plots and residuals *vs.* fit-plots.

Results

Area use

The reindeer mostly rested and ruminated (*i.e.* lying) repetitively at the same location. In the wind turbine enclosure, the majority of all lying activity was concentrated at one bedding site in 1999, in period 1 and 2 combined in 2000, and in period 3 and 4 combined in 2000 (Fig. 2). The site was on level ground dominated by graminoids. It was located at high elevation with a particularly good view, and close (100 m) to the wind turbine. The site was highly preferred, both when the rotor was moving and when it was turned off (Fig. 2). In 1999, no significant difference in use of this site was found between the periods of wind turbine rotor on or off. In period 1 and 2 in 2000, there was a significant increase in use from 49% to 90 % ($n = 44$; $\chi^2 = 9.34$, $P < 0.05$) with the rotor turned on,

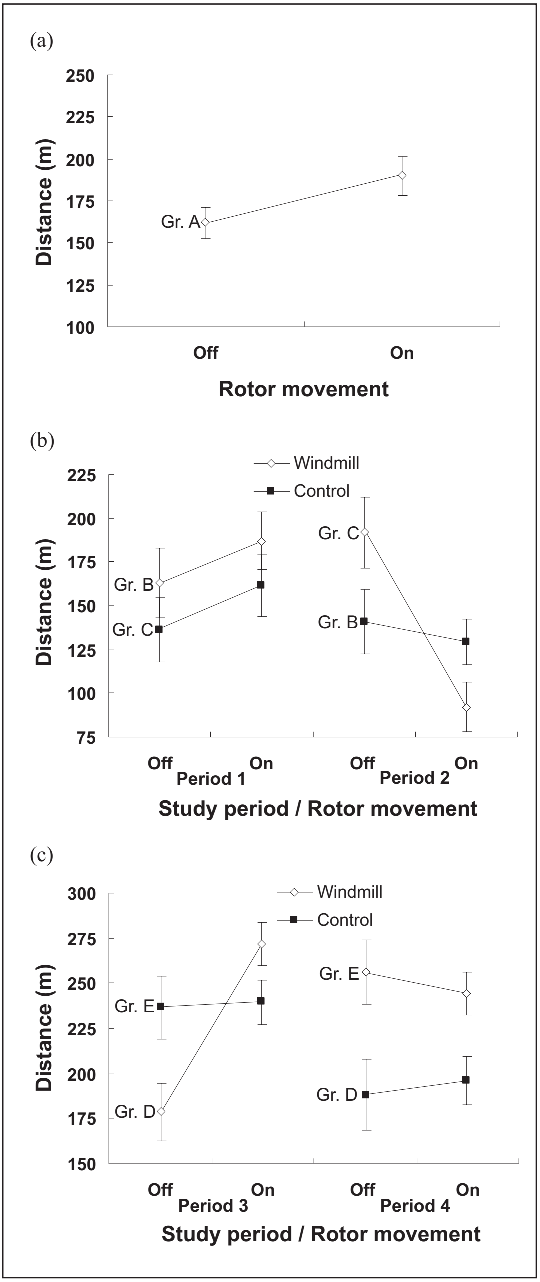

Fig. 3. Reindeer mean distance to the upper part of the enclosures and the wind turbine in relation to enclosure and rotor movement for (a) 1999, (b) 2000 period 1 and 2 and (c) 2000 period 3 and 4. Bars: standard error of the mean.

while in period 3 and 4 the result was opposite, with a decrease from 80% to 28% with the rotor turned on (n = 39; χ^2 = 8.19, P < 0.01). The favourite bedding sites of the different groups of control reindeer was in similar habitat, with high elevation, a good view and graminoid dominated vegetation.

During feeding bouts, the enclosures were used more uniformly by all groups, and no distinct locations of concentrated activity were registered. In 1999, significant effects were found for rotor movement (n = 207; F = 5.65, P < 0.05), wind direction (n = 207; F = 5.79, P < 0.001) and wind speed (n = 207; F = 6.47, P < 0.01) on the location of the reindeer in the wind turbine enclosure. The reindeer were located on average 28 m farther away from the wind turbine when the rotor was moving than when it was turned off (Fig. 3a). With a southwest wind direction and wind speeds more than 8 ms^{-1}, reindeer were located farther away from the wind turbine (against the wind) than during other wind directions and lower wind speeds.

In period 1 and 2 in 2000, there was a significant interacting effect of enclosure, rotor movement and reindeer group on the location of the reindeer (n = 215; F = 11.44, P < 0.001; Fig. 3b). In period 1, both the wind turbine and control reindeer were located farther down in the enclosure when the rotor was moving. In period 2, there was a marked difference between wind turbine and control, with the wind turbine reindeer being located on average 100 m closer to the wind turbine in the northeast end of the enclosure when the rotor was moving. Among the control reindeer, there was no significant difference in mean distance to the northeast end of the enclosure between periods of rotor movement on and off.

An interacting effect of enclosure, rotor movement and reindeer group on the location of the reindeer was also significant in period 3 and 4 in 2000 (n = 275; F = 5.29, P < 0.05; Fig. 3c). However, the trends in the results were different from period 1 and 2. In period 3, the wind turbine reindeer were located on average 93 m farther away from the wind turbine in the northeast end of the enclosure when the rotor was moving, while there was no significant difference in mean distance to the northeast end of the enclosure between periods of rotor movement on and off among the control reindeer. In period 4, there were only small differences between the wind turbine and control reindeer. Effects of wind speed and days of experiment on location of the reindeer were not found in any of the periods 1 to 4.

In summary, the area use during resting bouts in period 3 and 4 combined in 2000, during feeding bouts in 1999 and in period 3 in 2000 was shifted farther away from the wind turbine during rotor movement. During resting bouts in period 1 and 2 combined, and during feeding bouts in period 2 in 2000, the results were opposite, with area use shifted closer to the wind turbine during rotor movement. During resting bouts in 1999 and feeding bouts in period 1 and 4 in 2000, the rotor movement showed

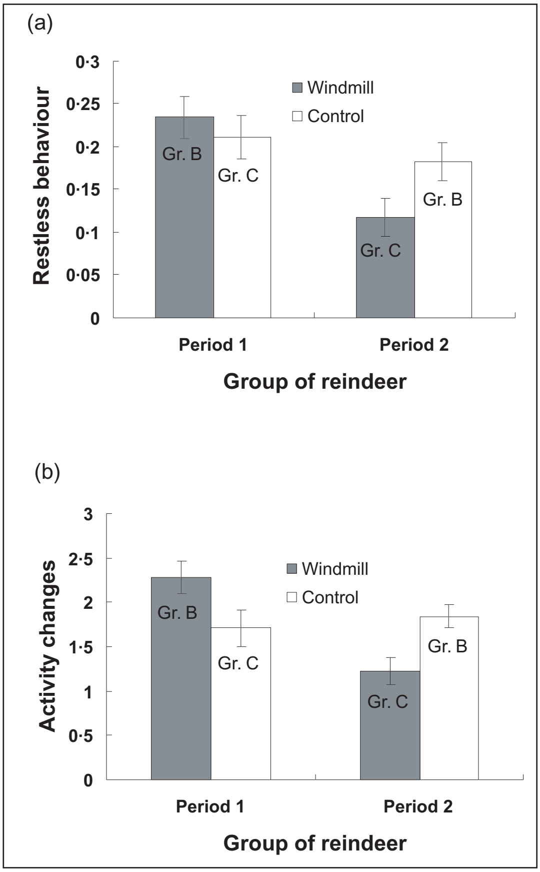

Fig. 4. The proportion of restless behaviour (a) and the frequency min^{-1} of activity changes (b), in relation to enclosure and reindeer group for period 1 and 2 in 2000. Bars: standard error of the mean.

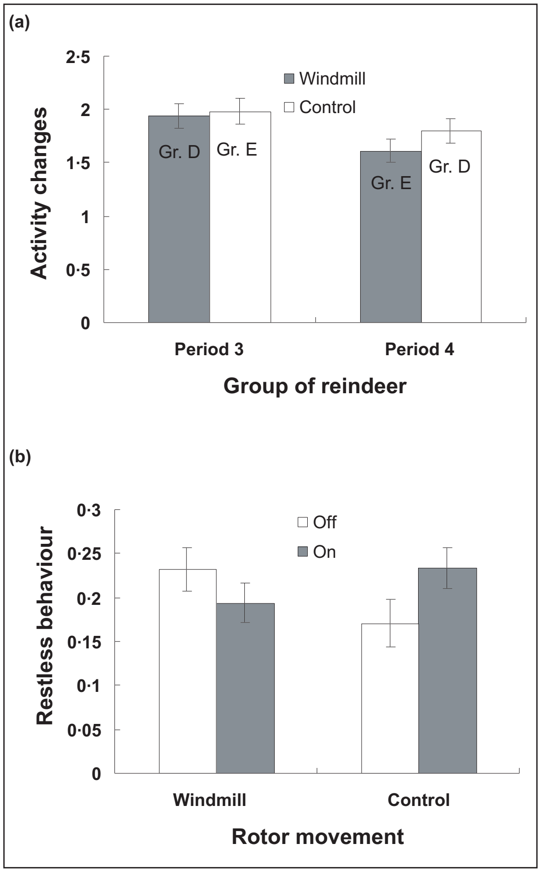

Fig. 5. The frequency (min^{-1}) of activity changes (a) in relation to enclosure and reindeer group, and the proportion of restless behaviour (b) in relation to enclosure and rotor movement for period 3 and 4 in 2000. Bars: standard error of the mean.

no effect on area use. No combined negative effect of rotor movement and wind speed was found.

There were no indications of habituation with changes in area use from the start and into later days of the experiment.

Behaviour

No instant changes in behaviour were observed in the short time period of 0–10 min directly after onset of the wind turbine rotor in any of the experimental periods. In 1999, the frequency of activity changes was lower when the wind turbine rotor was moving (n = 236; F = 7.46, P < 0.01), and when the wind direction was from northeast (blowing from the wind turbine) (n = 236; F = 4.10, P < 0.05). The frequency (± standard error of the mean) was 1.11± 0.073 min^{-1} at rotor movement and 1.36 ± 0.066 min^{-1} when the rotor was off. No variables were found to significantly affect the proportion of restless behaviour in 1999.

In period 1 and 2 in 2000, there was a significant interacting effect of enclosure (wind turbine and control) and reindeer group (B and D) on both the proportion of restless behaviour (n = 124; F = 7.33, P < 0.01; Fig. 4a) and the frequency of activity changes (n = 120; F = 13.2, P < 0.001; Fig. 4b). In period 1, group B in the wind turbine enclosure had more frequent activity changes and more restless behaviour than group C in the control enclosure. After the cross-over in period 2, group B, now in the control enclosure, maintained more frequent activity changes and restless behaviour than group C. The difference between the two groups of reindeer was larger than the difference between wind turbine and control, with group B having an overall frequency of activity changes of 2.06 min^{-1} and group C having an overall frequency of 1.47 min^{-1} (n = 124; F = 12.1, P < 0.001). No effects on behaviour from wind turbine rotor movement, wind speed or days of experiment were found in period 1 and 2.

In period 3 and 4 in 2000, the reindeer showed different behavioural responses than in period 1 and 2. A significant interacting effect of enclosure and reindeer group on the frequency of activity changes was found (n = 258; F = 4.86, P < 0.05), but it showed no higher frequency in the wind turbine than in the control enclosure (Fig. 5a). For restless behaviour, a significant interacting effect of enclosure and rotor movement was found (n = 325; F = 5.74, P < 0.05; Fig. 5b). The reindeer were less restless when the rotor was moving than when it was turned off in the wind turbine enclosure. In the control enclosure, this was opposite, with the reindeer behaving more restless in the time periods of rotor movement. For both activity changes (n = 258; F = 4.37, P < 0.05) and restless behaviour (n = 325; F = 4.36, P < 0.01), there were significant effects found for the interaction between rotor movement and wind speed, but the effect of wind and rotor movement was not different in the wind turbine enclosure compared to the control.

Vigilance behaviour was only recorded for group D and E, and we found a significant interacting effect of enclosure, rotor movement and reindeer group on the vigilance frequency (n = 193; F = 6.12, P < 0.01; Table 2). In period 3, group D in the wind turbine enclosure had a higher vigilance frequency with the rotor moving than with the rotor turned off, but the same tendency was stronger with group E in the control enclosure, indicating no increasing effect of rotor movement on the vigilance. In period 4, the tendency was opposite for both the wind turbine and control groups, with lower vigilance frequency when the rotor was moving. No effect of the experimental day was found for the behaviour of the reindeer in period 3 and 4.

In summary, the behaviour of the reindeer was affected by different variables in a nonsystematic way. In general, negative effects of wind turbine and rotor movement were not found. There was no indication of habituation with changed behaviour in later days of the experiment.

Discussion

Effects of the wind turbine

The reindeer showed some indications of a shift towards use of locations at longer distance from the wind turbine when the rotor movement was on. This was observed for resting bouts in period 3 and 4 in 2000 and for active behaviour in 1999 and period 3 in 2000. However, the opposite, with a shift towards use of areas closer to the wind turbine, was observed for resting bouts in period 1 and 2 and for active behaviour in period 2 in 2000. Because of handling problems with the experimental animals in period 1 and 2, the results from these periods should be evaluated with caution. We can not exclude the possibility of confounding effects from different handling of animals prior to the experiment in period 1 and 2, and an injured animal in the wind turbine enclosure in period 2. Reindeer area use in the wind turbine enclosure in period 2 differed from the other periods, but we did not observe any obvious relationship between this result and the hoof injury of the animal.

When considering all the experimental periods and groups of reindeer, the behaviour seemed highly variable, with significant effects of different variables in the different periods of the study. From the hypothesis of a disturbing effect, we expected increased levels of restless behaviour, activity changes and vigilance when the reindeer were exposed to the wind turbine and rotor movement. Overall, this was not observed.

Increased activity and energy expenditure may occur if reindeer continue grazing in an area despite extensive human disturbance. In oil-fields in North-America, caribou have been shown to increase their movement rates and reduce the time allocated to feeding when exposed to roads with vehicle traffic, pipelines and noise from petroleum exploration (Curatolo & Murphy, 1986; Murphy & Curatolo, 1986; Bradshaw *et al.*, 1997). Reindeer respond with fright and flight whenever humans are detected within a certain distance (Eftestøl, 1998; Colman *et al*, 2001). Behavioural responses of this kind may result in negative effects on the energy budget of the animals (Reimers, 1980; Tyler, 1991; Bradshaw *et al*, 1998, Colman *et al*, 2003). If the activity budget is skewed towards energy expending activities with less time spent feeding, the body weight and physical condition of the individual animals will eventually be reduced, as has been shown for reindeer during the hunting (Reimers & Kolle, 1987; Skogland & Grøvan, 1988) and insect (Colman, 2000, Colman *et al*, 2003) seasons in southern Norway. Since energy expending behavioural responses were generally not observed in connection with the onset of the wind turbine rotor, the reindeer probably did not associate the wind turbine with instant danger. The overall tendencies of our results indicate no effect of the wind turbine on reindeer area use and behaviour.

The wind turbine is a permanent construction that reindeer were continuously exposed to during the experiment. Since we waited minimum 12 hours after release of the reindeer in the enclosures before beginning our observations, habituation towards the wind turbine could already have begun, making it difficult to observe a possible disturbing effect of the wind turbine followed by normalised behaviour later on. However, onset of the wind turbine rotor began minimum three days after the reindeer had been released in the enclosure, and did not induce any fright or stress response, even though the reindeer had no prior experience with this stimulus. Furthermore, there was a general lack of negative behavioural effects of wind speed that are also related to the noise level of the wind turbine rotation (Wagner *et al.*, 1996).

There have been several studies on *Rangifer* behaviour when exposed to moving and noise generating objects. Among the results are increase in vigilance when exposed to humans on foot (Duchesne *et al.*, 2000), fright and flight responses in exposure of snowmobiles (Tyler, 1991; Mahoney *et al.*, 2001; Reimers *et al.*, 2003) and humans on foot (Colman *et al.*, 2001; Eftestøl, 1998), and startle responses (Harrington & Veitch, 1991), increased movement rates (Maier *et al.*, 1998) and heart rates (Berntsen, 1996) in exposure of overflights from jet-fighters or helicopters.

On the other hand, there are not many studies on *Rangifer* behavioural effects of direct exposure to permanent constructions. In Prudhoe Bay oil field in Alaska, Curatolo & Murphy (1986) and Murphy & Curatolo (1986) found negative effects on the activity budget of caribou, with a decrease in the time spent lying and an increase in time spent standing, walking and running within 600 m of a pipeline paralleled by a road with traffic and within 300 m of a pipeline paralleled by a road without traffic. There was a decrease in the crossing frequency, but only under pipelines that were paralleled by roads with traffic. The effects were not significant in periods with insect harassment. Caribou have been reported to use roads, gravel pads and shading constructions inside the Prudhoe Bay oil field for insect relief on hot days with high levels of insect harassment (Curatolo & Murphy, 1986; Pollard *et al.*, 1996; Noel *et al.*, 1998). Thus, the constructions seem to have a limited or weak disturbing effect that eventually disappears when insects are the dominant disturbing factor. Our results do not indicate disturbing effects of the wind turbine rotation. Although it is a construction with a movable object, it is probably not associated by a direct risk of predation by reindeer. Vehicles, aircrafts or humans on foot are more likely to induce anti-predatory behavioural responses. Human activities in the area of a wind turbine park are likely to have stronger effects on reindeer than the constructions themselves. A short period of construction, concentrated in seasons without reindeer in the area, and limited human activity after establishment of a wind turbine park, is probably essential in order to minimise potential negative effects. If the level of human activity in an area is high, reindeer may learn to associate the area with danger regardless of the existence of wind turbines.

Johnson *et al.* (2000) found no difference in abundance of pronghorns within 800 m of a wind turbine park when comparing data from before and after construction. Occasional observations from Lammasoaivi wind turbine park in Finland (V. Kokkonen, pers. comm.), and from Rodovålen wind turbine park in Sweden (Anonymous, 2000) suggests no negative effects of wind turbines on domestic reindeer in these areas. It should be noted that the windmill park in Lammasoaivi is located on a rocky outcrop and reindeer may react differently if windmills were located within preferred habitat. The overall tendencies of our study are in accordance with this, and thus, short-term negative effects of wind turbines on reindeer can not be supported. On the other hand, Sami reindeer pastoralists claim that their herds do not calm down while grazing in the area of Vikna wind turbine park (R. Anti, pers. comm.). In light of this, it is important to keep in mind that the limited knowledge from occasional observations and proximate effects of a wind turbine on reindeer inside an 8 hectars enclosure can not be directly extrapolated to free-ranging reindeer. Free-ranging reindeer will only occasionally be exposed to human constructions, and they are free to move away from the constructions after short exposure times (*e.g.* in connection with migration routes). Thus, their behaviour and reactions towards wind turbine parks may differ considerably from this study.

Cumulative effects of human developments and activity

It is possible that *Rangifer* avoidance responses occur in larger geographical perspective towards human developments, but it is less obvious how much area is likely to be avoided, and whether long-time habituation or population growth may reintroduce animals into temporarily abandoned areas (Bergerud *et al.*, 1984). Although direct exposure to permanent technical constructions without humans being present do not seem to induce major fright or stress responses in *Rangifer*, the animals may learn to associate the constructions, or infrastructure in general, with increased levels of human activity, and thereby avoid or decrease the use of adjacent areas as an anti-predator strategy. The cumulative effect of hunting, tourism, and technical constructions may result in avoidance of large areas. Our study was not designed to reveal such an effect of a wind turbine park.

Future studies

Understanding the implications of human disturbance for reindeer and caribou requires assessment of cumulative effects at annual, population and regional scales (Wolfe *et al.*, 2000). We show no direct, negative local effects of a wind turbine on reindeer behaviour. Comparable experimental studies are needed to confirm this finding. A main challenge when doing manipulative experiments with reindeer is to reduce eventual negative effects of human handling on these animals. A sample size with enough power to reveal possible effects is also necessary. However, this is costly and time-consuming when doing research on such a large species.

The cumulative effect of a wind turbine park and the human activity associated with such parks, along with previous human disturbance in an area, can not be fully assessed in the type of study presented here. We concentrated at the individual and group level, focusing on specific, short term behavioural aspects of reindeer reactions towards windmills at close range. Future studies should include group and population aspects on a regional scale. In such regional studies, it is also necessary to document the area use of populations before, during, and after establishment of a wind turbine park in order to reveal eventual avoidance, and perhaps re-use after short-term abandonment. Several methods are available for estimating animal distribution in the field, including line transect surveys of animals, tracks, or dung (Marques, *et al.*, 2001), aerial surveys along transects (Pollard, *et al.*, 1996), and GPS/VHF tracking (Haller, 2001). Studies on area use of the animals should be continued in subsequent decades in order to reveal if areas are only temporarily abandoned (Bergerud *et al.*, 1984).

Conclusion

Our study showed ambiguous effects of the movement and noise of the wind turbine rotor on the area use of reindeer in an enclosure located from 10 to 450 m from the wind turbine. Reindeer behaviour was not systematically different when comparing animals in the wind turbine enclosure with those in a control enclosure, suggesting that the level of fright and/or stress was not higher for the exposed reindeer. Since other studies have found negative effects of human developments and activity on regional area use of free-ranging *Rangifer*, future studies on possible effects of wind turbines on reindeer need to include this aspect.

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Abstract in Norwegian / Sammendrag:

I løpet av de senere tiår har industriell utbygging til utnytting av energi, mineraler, tømmer og andre ressurser ekspandert inn i reinens beiteområder i nordområdene. Flere vindmølleparker er under planlegging i norske reinbeiteområder, og det spekuleres i mulige konsekvenser av disse på atferd og arealbruk hos villrein og tamrein. Vi testet om en vindmølle og dens rotorbevegelse hadde noen effekt på arealbruk, aktivitetsskifter, vaktsomhetsatferd, og rastløshetsatferd i form av løp, gange og ståing for tamrein i innhegning. I en 450 m lang innhegning på 8 hektar som var plassert tett opp til en vindmølle, ble fem forskjellig grupper av reinsdyr manipulert ved å slå vindmøllerotoren av og på. Reinsdyrene i innhegningen ved vindmøllen ble sammenlignet med reinsdyr i en kontrollinnhegning som var uten påvirkning fra vindmøller. Når reinsdyrene ble utsatt for vindmøllerotoren i bevegelse, viste to grupper av dyr et skifte i arealbruk til områder av innhegningen som var lenger unna møllen, to grupper av dyr viste ikke noe skifte i arealbruk, mens en gruppe dyr beveget seg nærmere vindmøllen. Sammenligning av atferden hos reinsdyrene i vindmølleinnhegningen og kontrollinnhegningen viste ingen systematisk forskjell som kunne indikere frykt eller stress som en effekt av vindmøllen eller rotorbevegelsen. Vi konkluderer med at tamrein i innhegning ikke viser negative atferdsresponser og viser lite eller ingen reduksjon i arealbruken tett opp til en vindmølle. Muligheten for at det skjer en rask tilvenning i en liten innhegning der dyrene er i kontinuerlig påvirkning av vindmøllen betyr at effekter på arealbruk bør studeres i et større arealperspektiv eller på frittgående rein.